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Why is there no cannery in 'Cannery Row'? Exploring a behavioral simulation model of population extinction

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Available ecological models of organizations do not provide satisfactory explanation for population extinction. In this article, we search for a minimal set of assumptions needed to expand the range of dynamic behaviors of the ecological model of density dependence to admit extinction while preserving its original insight. The revised version of the model builds on two core assumptions. The first is that organizational populations are linked to their environments through feedback processes of resource generation and consumption. As a consequence, the carrying capacity for an organizational population changes systematically with its density. The second assumption is that organizational vital rates respond with delay to changes in the level of available resources. As a consequence, organizational founding and mortality rates are affected by expectations that decision makers form about the future state of their environment. Using computer simulation, we test these assumptions and show that the relative speed at which processes of resource regeneration and consumption happen, and the speed at which expectations about future levels of resources are revised jointly determine a wide range of evolutionary trajectories that admit population extinction as one distinct possibility. The model is validated using multivariate sensitivity analysis techniques. We discuss the implications of our findings in the broader context of the current debate on the implications of selective sampling in the study of organizational populations.

JEL classification: C60, M20, Z13.

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1. Introduction

In 1902, Frank Booth moved from Pittsburgh to Monterey Bay, California, to found the F.E. Booth Company—a sardine canning plant. By most accounts, this date marks the legendary beginning of Monterey's sardine industry: Cannery Row is officially born and Frank Booth becomes the "father" of the sardine canning industry.[1] In 1904, Booth recruited an accomplished Sicilian fisherman, Pietro ("Pete") Ferrante who, in turn, invited his brother-in-law and several members of his extended family to join him in Monterey from Palermo, Sicily. The second cannery, the Monterey Fishing and Packing Company, was established two years later in 1906. World War I created an international market for tinned sardines. By the end of World War I, there were nine canneries in Monterey forming a continuous row of factories along the waterfront. By the 1930s, Monterey was considered the sardine capital of the world and the sardine fishery in California was estimated to be the largest in the Western hemisphere.

In the 1936–1937 fishing season, more than 206 thousand tons of sardines were caught in Monterey Bay and the canneries in Cannery Row produced almost 3 million cases of canned sardines. In 1950, there were 31 canneries in operation. By the early 1950s, sardines disappeared from Monterey for causes that are still object of debate among marine biologists. In 1957, the sardine catch was only 17 thousand tons. By 1961, only five plants remained. The last sardines in Cannery Row were packed in 1964.[2] Interestingly, the number of fishing vessels in Monterey continued to increase as the catch declined. There were 321 fishing vessels in Monterey in 1936–1937 (316 of which were sardine vessels). By the time the catch stared to decline in 1948, a total of 395 vessels were fishing in Monterey. A fleet of 473 fishing vessels operated in Monterey bay in 1957.

Figure 1 summarizes our story. The carrying capacity of the population of canneries (measured in tons of sardines) changes considerably over time. After the 1940s, the number of canneries increased rapidly as the carrying capacity began to collapse. The population of canneries declined equally rapidly with a delay of approximately two years. A small recovery of the catch right before 1960 resulted in an ephemeral period of stabilization of the organizational population at lower levels of density. By 1964, it was all over: no sardines, no canneries.

This piece of local industrial history immortalized in John Steinbeck's famed book seems to suggest a rather direct answer to the factual question posed in the title: There is no cannery in Cannery Row because there are no more sardines to be canned. The local organizational population went extinct because the resources

[1]See McEvoy (1983) for a less idiosyncratic account of the historical development of the California fisheries.

[2]The *Hovden Food Product Corporation* survived few more years by canning squid but was forced to close in 1973.

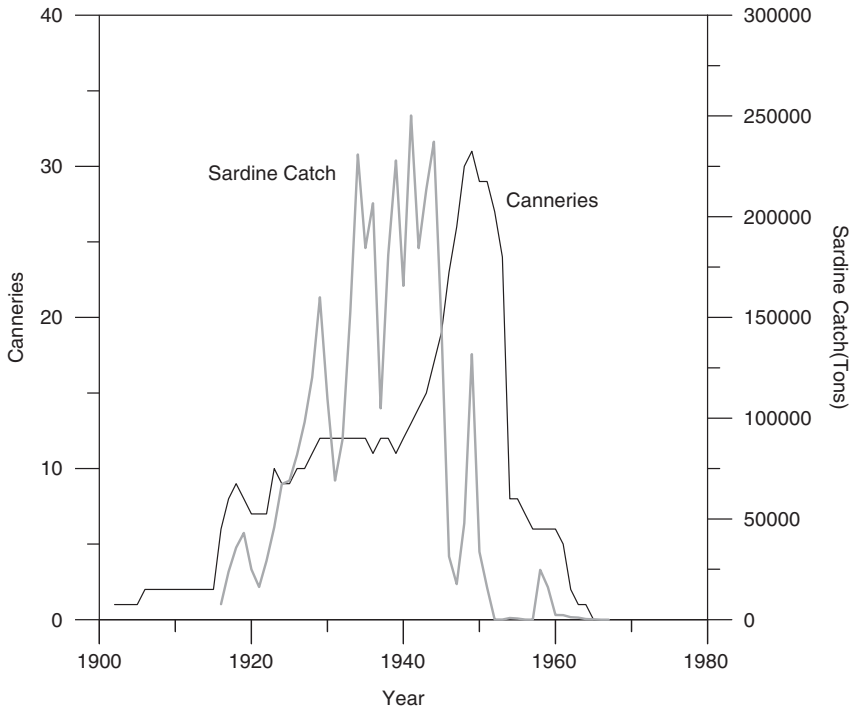

Figure 1 Time series plots of number of canneries in Cannery Row (thinner black line) and tons of sardine caught in Monterey bay (thicker grey line). Data on canneries were reconstructed on the basis of various historical sources. Data on sardine catch are taken from Ueber and McCall (1992) and Radovich (1982). Plots are reported on a double scale.

that sustained its existence became insufficient and eventually disappeared altogether.

How do demographic models of organizations incorporate this deceivingly simple observation on the extinction of organizational populations? Rather surprisingly they do not. In Cannery Row, the number of organizations that the local environment sustained was clearly determined by the carrying capacity measured in terms of tons of sardines harvested. The decline in number of canneries was driven by the dramatic contraction of their resource base. This is one aspect of the overall explanation for extinction that is well understood in demographic theories of organizations (Carroll and Hannan, 2000). Yet, in our motivating example the carrying capacity for the population is not exogenous, but itself dependent on the number of organizations that are present, and possibly on the technology they employed.[3] These aspects of the overall explanation of organizational extinction are not well captured

[3]For example, Pete Ferrante imported from the Mediterranean the new "Lampara method" of fishing which increased efficiency of fishing efforts thus providing more stable input to the cannery.

by ecological models of organizations (Carroll and Hannan, 2000: Chapter 2.4; Ruef, 2004b).

The main objective of this article is to propose and test a model of extinction that fills an evident conceptual gap in our current understanding of the evolutionary dynamics of organizational populations. Building on earlier work by Lomi *et al.* (2005), we propose a simple model that makes two fundamental assumptions about how organizations and their environments interact. The first assumption is that the carrying capacity for an organizational population is not fixed, but systematically affected by density—the number of organizations in a population. The model posits that density affects the carrying capacity through two opposing processes. The first involves the consumption of resources: organizations deplete the carrying capacity by consuming the resources needed for their material survival. The second process involves the regeneration of resources: organizations contribute to the carrying capacity by producing resources that other organizations may be able to use. As a consequence the availability of resources for an organizational population is not constant, but depends endogenously on the number of existing organizations and their capacity to generate resources. Our motivating example again can be used to illustrate the point: starting from the mid-1980s sardines reappeared in Monterey following two decades of careful natural resource management programs that established quotas and supported repopulation programs. *The New York Times* (2005) reports that in 2004 about 50,000 tons of sardines were landed off California.

The second assumption is that changes in the level of available resources affect organizational vital rates with at least some delay. In the case of organizational founding rates, this assumption is based on results produced by recent research on preproduction and on the time delay between conception of a new organization and its actual creation (Sørensen and Sorenson, 2003; Jovanovic, 2004; Carroll and Khessina, 2005; Lomi *et al.*, 2010). The delayed effects of change in the level of available resources on organizational mortality rates derive from the view of organizations as capital investment projects that involve initial commitments and uncertain future returns (Sutton, 1991; Dixit, 1992). Mortality (or "divestment") delays are systematically produced by a combination of irreversibility in initial investments, and uncertainty about the level of resources that may become available in the future (Bernanke, 1983). As our motivating example clearly illustrates, the organizational population reacted with considerable delay to the contraction of its resource base.

We extend ecological and demographic theories of organizations by showing how models of density dependence that incorporate these two assumptions may be able to account for a richer range of dynamic behaviors which include extinction as a distinct possibility. In retrospective empirical studies, the full range of possible

The new methods made fishing efforts more efficient and lucrative, and attracted more fishing companies to Monterey.

evolutionary trajectories cannot be observed and analysis is necessarily limited to the realized historical trajectory—or to a small area in the large space of historical alternatives (Carroll and Harrison, 1994; Denrell and Kovacs, 2008). In this article, we use numerical simulation techniques to examine whether and how the ecological model of density dependence can be enriched to generate extinction trajectories. We search for a plausible set of assumptions that would be needed in order for the *same* model to be able to produce both "history-divergent" outcomes that result in extinction trajectories, as well as "history friendly" outcomes that result in evolutionary trajectories more commonly observed in studies of actual organizational populations (Malerba *et al.*, 1999). Following established principles of behavioral simulation modeling, we perform a series of virtual experiments to understand the conditions under which the feedback connection linking organizations to their environments may produce population extinction (Morecroft, 1985). We report results that help to forward and refine the current debate on the possible implications of selective sampling in the study of organizational populations.

2. Motivation and background

2.1. How many kinds of organizations are there, and why does it matter?

According to Newman and Palmer (2003:1):

> Of the estimated one to four billion species which have existed on the Earth since life first appeared here, less than 50 million are still alive today. All the others became extinct, typically within about ten million years of their first appearance.

Limitations in data availability, conceptual difficulties in identifying precisely how selection operates on "individuals" ("organizations") and "species" (or "forms"), and an inveterate tendency to emphasize short-term change have so far precluded the possibility of reaching similar conclusions in the study of organizational populations. A crucial question for evolutionary biologists concerns the *number* of species (May, 1988). Processes of extinction are of direct relevance to fundamental questions about the diversity of life forms (May, 1988), but why should the extinction of organizational populations be of any interest to organization theorists? While we think that ecological processes of organizational extinction are interesting in their own right, their study can also help to elucidate three more general theoretical problems that are currently open in the study of organizational populations.

First, a major reason for developing an organizational ecology was to understand the dynamics of diversity in the organizational world (Stinchcombe, 1965; Hannan and Freeman, 1977). During the last three decades, however, studies inspired by ecological theories of organizations have concentrated almost exclusively on quantitative aspects diversity, i.e. on variations in rates of organizational funding, disbanding, growth and change (Shipilov and Baum, 2006). Relatively little is still

known about processes underlying the dynamics of qualitative diversity, i.e. about the forces that control rates of organizational speciation and extinction. While current efforts are being made to illuminate specific issues in form emergence (Ruef, 2000), only a limited amount of research is available on processes of population extinction (Ruef, 2004b). In this article, we want to make a preliminary step in the direction of narrowing this notable conceptual gap.

Second, and more pragmatically, extinction may be viewed as an extreme case of population oscillation and decline—evolutionary trajectories that are frequently observed in actual organizational populations, but not well explained by available models without the addition of a number of auxiliary assumptions (Hannan, 1997; Ruef, 2004a). Original models of density-dependence, for example, imply that organizational populations grow to steady state density (Hannan and Carroll, 1992). In most cases, however, this assumption does not fit empirical observations well (Carroll and Hannan, 2000). Organizational populations frequently decline sharply after reaching their peak, and then fluctuate for variable periods of time before stabilizing at lower levels of density. A variety of specialized models have been offered to explain such fluctuations like, for example, models of time-heterogeneity (Hannan, 1997), mass-dependence (Barnett, 1997), density delay (Carroll and Hannan, 1989), system dependence (Lomi *et al.*, 2005) and population-level inertia (Ruef, 2004a). No consensus has been reached, however, on the specific mechanisms behind observed fluctuations in density. Theoretically inspired models of extinction may provide important insight on the causal structure of more general processes of population decline (Ruef, 2004b).

Third, recent research has argued that results of empirical studies on organizational populations are invalidated by sample selection problems. According to this view, empirical results are unreliable because: "It is not clear if the studied populations are representative of the set of populations to which the theory is supposed to apply" (Denrell and Kovacs, 2008: 125). Organizational populations that make it into empirical studies are unusual in the sense that they are unusually large, important, and long-lived. This argument cannot be developed much further without making assumptions about the forces that may drive organizational populations to extinction as: "It seems reasonable to assume that only a fraction of the organizational populations that have ever existed have reached densities as high as those" that have been actually studied (Denrell and Kovacs, 2008: 127). The model that we present in this article makes these assumptions explicit and hence amenable to direct investigation. Our objective is to provide a model that admits extinction as a distinct historical possibility among many others.

2.2 Understanding extinction

Two main approaches can be identified to modeling extinction processes. The first is based on the view that extinction is the consequence of rapid exogenous change in

environmental or competitive conditions that make existing organisms "run out of niche" (Maynard Smith, 1989). According to this view, extinction has physical causes. In the study of organizational populations, this explanation is frequently based on considerations of technological or institutional discontinuities (Tushman and Anderson, 1986). For example, the New England Ice Economy based on the harvesting of natural ice ended not because the demand for ice declined, but because in 1868 the Louisiana Ice Manufacturing Company opened the first artificial ice manufacturing plant after obtaining a patent to produce ice using gas and compression technologies. Similarly, in 1920, US breweries did not all cease to exist at the same time because demand for beer suddenly dropped to zero, but because the Federal Prohibition era began (Carroll and Swaminathan, 1991).

While technological and institutional discontinuities represent obviously relevant extinction contingencies, attributing the extinction of organizational populations exclusively to exogenous technological and institutional change does not seem to represent a generally appealing solution for at least three related reasons (Ruef, 2004b). The first reason is empirical: Ecological research has documented that the effects of endogenous population processes on organizational vital rates are stronger, more consistent and more predictable than the effects of exogenous environmenttal factors (Hannan, 1997). The second reason is historical: Populations that have faced remarkably different competitive and institutional conditions such as, for example, banks, brewing companies and labor unions tend to respond similarly to the same endogenous population-level processes (Hannan and Carroll, 1992). The third reason is institutional: population-level processes are frequently shown to affect the general institutional framework that shapes organizational life chances. For example, Ingram and Rao (2004) showed that density-dependent processes in the population of independent retailers in the United States significantly affected the propensity of States to enact anti chain store legislation.

In the next section of the article, we build on a second approach to extinction based on the view that extinction has "biotic" (rather than physical) causes (Maynard Smith, 1989). According to this view: "Extinction is a natural part of the dynamics of ecosystems and would take place regardless of any stresses arising from the environment" (Newman and Palmer, 2003). This view invites reflection on the possibility of endogenous causes of extinction due to interaction between species (or organizational populations in our case), or between species and their environmental resources (Maynard Smith, 1989). According to the model that we propose organizational populations may disappear for physical causes—because they "run out of niche," as it were. But the capacity of the niche to sustain the population is not independent from fundamental population-level processes of resource consumption and production that depend on density (Lomi*et al.*, 2005). Our objective is to propose a model in which extinction may "take place regardless of any stresses arising from the environment."

3. A dynamic feedback model of population extinction

The baseline model of population growth used in corporate demography specifies the population growth rate in terms of birth (λ) and mortality (μ) rates that are both assumed to depend on density (N_t)—the number of organizations in the population. The demographic dynamics of the population is defined by the recursive relation:

$$N_t = N_{t-1} + \lambda(N_t) - \mu(N_t). \tag{1}$$

Different forms for λ and μ determine how fast the population will reach its carrying capacity (K) which in the model appears only as an implicit (fixed) constraint on the rate of growth of N_t because it is assumed that:

$$\mathrm{d}N/\mathrm{d}t = gN_t(1 - N_t/K), \tag{2}$$

where g is the so called natural rate of population growth, i.e. the rate at which the population grows when density is sufficiently distant from the carrying capacity.

Ecological theories of organizations suggest specific non-linear functional forms for $\lambda(N_t)$ and $\mu(N_t)$ that are now supported by more than 25 years of empirical research conducted on a variety of organizational populations (Carroll and Hannan, 2000). For example, the systematic components of the functional relation linking organizational founding and mortality rates to changes in population density are, respectively (Hannan and Carroll, 1992, Chapter 4 and Chapter 6):

$$\lambda(N_t) = \exp(\beta_1 N_t + \beta_2 N_t^2), \quad \text{where} \quad \beta_1 > 0 \quad \text{and} \quad \beta_2 < 0, \quad \text{and} \tag{3a}$$

$$\mu(N_t) = \exp(\theta_1 N_t + \theta_2 N_t^2), \quad \text{where} \quad \theta_1 < 0 \quad \text{and,} \quad \theta_2 > 0. \tag{3b}$$

In this formulation, population density is represented as a stock variable whose level is determined by the specific values of an inflow (λ) and an outflow (μ) rates (given an initial condition N_{t_0}). Since inflow and outflow rates are assumed to depend on density, the baseline model of population growth assumed by empirical studies of corporate demography may be represented as a (first-order) feedback system (Sterman, 2000).

The ecological system of density dependence involves two feedback processes. The first is positive: As density increases from its initial low level, collective experience with new organizational forms and practices progressively diffuses, thus accelerating rates of organizational founding. As a consequence density increases further. The second loop is negative: above a given (population-specific) threshold of density further increases trigger competition and increase mortality rates. Other conditions being equal, increases in organizational mortality rates decrease the level of density. This feedback translation of density dependence is summarized by the "legitimation" and "competition" loops represented in Figure 2 which is based on the notation suggested by Sterman for feedback loop diagrams (2000). The signs placed next to

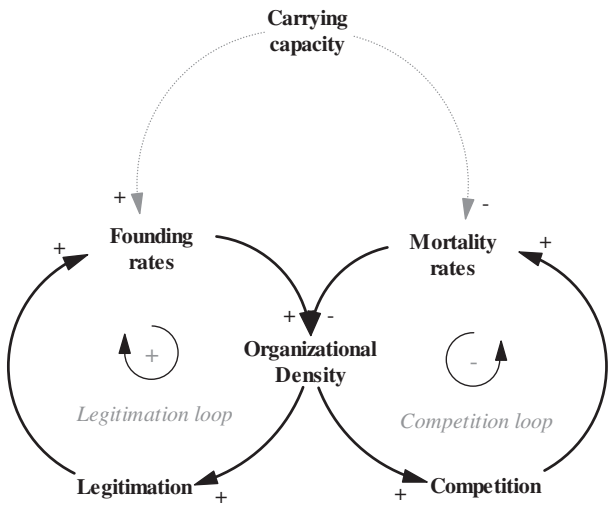

Figure 2 Density dependence as a feedback system.

the arrowheads ("+" or "−") indicate the direction of the causal connection linking the origin and the destination variable. More precisely, a positive sign next to the arrow connecting two variables ($X \rightarrow^{+} Y$) indicates that $\partial Y/\partial X > 0$. A negative sign next to the arrow connecting two variables ($X \rightarrow^{-} Y$) indicates that $\partial Y/\partial X < 0$. Following generally accepted conventions (Sterman, 2000), the symbols ("+" or "−") placed at the center of a feedback loop indicates its polarity: "+" for *positive* (or "Reinforcing") or "−" for *negative* (or "Balancing"). As Figure 2 illustrates, in this representation the role of resources is only implicit: The carrying capacity sets the ultimate limits to growth for the organizational population by directly affecting organizational vital rates, but its level is not determined within the model.

This way of representing the carrying capacity is a valuable first approximation of the relation between organizations and their environments, but it is unlikely to exhaust the range of possibilities, particularly given the "*long durée*" of ecological studies which not infrequently span centuries of economic, social, cultural, and technological evolution and revolutions. The basic conceptual problem seems to be that in the feedback system of density dependence that we have described organizational density can only evolve to steady state. Since it implies a first-order dynamic system, the model of density dependence is simply unable to capture the complete variety of historical trajectories that are actually observed (Sterman, 2000). Organizational populations, for example, are recurrently observed to collapse after peak, oscillate for variable period of time, and—occasionally—resurge (Hannan, 1997; Carroll and Hannan, 2000; Ruef, 2006). Organizational populations occasionally may—and probably do—go extinct (Dnerell and Kovacs, 2008).

Our attempt to make the basic model of density dependence more expressive starts by assuming that the carrying capacity (K) may change over time as a function of density so that:

$$\frac{dK}{dt} = \omega_t K_t - \rho_t N_t, \tag{4}$$

where ρ is the resource consumption rate, i.e. the "claim" or "weight" that the average member of the population makes on available environmental resources (Winter, 1990), and ω_t is the resource regeneration rate, i.e. the amount of resources that the average member of the population contributes to the carrying capacity (Lomi *et al.*, 2005). In this formulation, $\rho_t N_t$ is the total amount of resources consumed by the population at time t and $\omega_t K_t$is the total amount of resources that the population contributes to the carrying capacity.

This assumption transforms the carrying capacity in the second stock variable whose level is determined within the model. More specifically, the level of available resources now depends on two additional positive feedback loops. The first is the *Resource consumption loop*: as organizational density increases, the overall burden imposed by the population on the carrying capacity also increases. Organizational mortality rates in the population are likely to increase. Other conditions being equal population density decreases as a consequence. Thus, the aggregate effect of the resource consumption loop is to add a second balancing feedback process which compounds the effects of density-dependent competition on organizational mortality rates and slows down population growth further. The second is the *Resource regeneration loop:* as density increases the aggregate resource generation capacity of the population increases. This results in higher levels of available resources and therefore in a higher carrying capacity. Organizational founding rates increase, and, other conditions being equal, population density will increase. So the aggregate effect of the resource regeneration loop is to reinforce the effect of legitimation on organizational founding rates. This discussion is summarized by the feedback loop diagram in Figure 3 which adopts the same graphical conventions already described for Figure 2.

The two short parallel segments indicate the presence of delays in the causal connections linking consumption and regeneration rates to the carrying capacity (Sterman, 2000). Keeping delays explicitly into account is necessary because processes of resource production and consumption are not instantaneous but can only happen over time (Lomi *et al.*, 2010).

This representation is based on two main assumptions each suggesting clear departures from received ecological models of density dependence. The first assumption is that the overall stock of available resources is both depleted and replenished by existing organizations. This assumption about how the carrying capacity may change over time is based on a mix of conventional and less conventional observations. The conventional observation concerns the resource consumption aspects

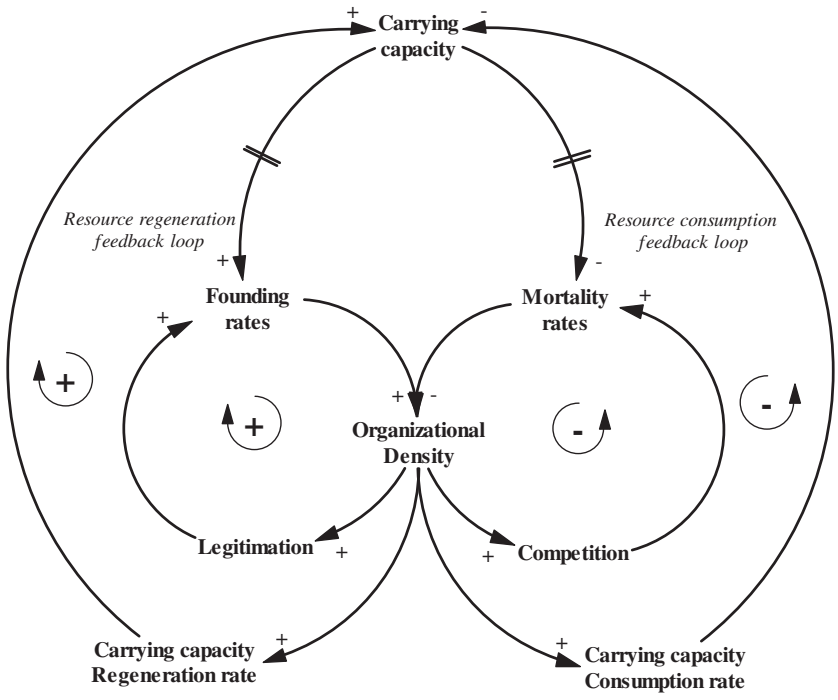

Figure 3 Feedback loop diagram representation of the modified model of density dependence.

of equation (3). Consider human resources, for example. All organizations need ("consume") human resources. Recruitment-based competition for scarce human resources (Sørensen, 1999) constrains organizational survival and growth precisely because organizations consume their human resources while preventing concurrent consumption of the same resources by other organizations. Other conditions being equal, the stock of available human resources decreases as organizational density increases.

The less conventional observation underlying our argument concerns the resource regeneration aspects of Equation (4) according to which organizations not only deplete the stock of available resources, but also contribute actively to the carrying capacity by producing resources that other organizations may be able to use. Consider, again, human resources. Like other kinds of knowledge-intensive organizations, universities employ ("consume") specialized human resources. Unlike other kind of organizations, however, universities also produce such resources for the use of other, possibly competing universities. As a consequence, the availability of resources for a population of organizations (universities in our example) is not constant, but depends endogenously on the number of existing universities and their investment in capacity for producing academics.

In summary, our argument is based on the stylized fact that not only do organizations depend on the availability, procurement, and consumption of environmental resources, but they also participate actively in the production and construction of such resources. This argument is frequently left implicit in organizational research, but is not in itself unusual. For example, extant research commonly recognizes that organizations modify elements of their general environment traditionally treated as exogenous—such as regulation and legal rules (Edelman *et al.*, 1999; Ingram and Rao, 2004). The implications of this argument for the evolutionary dynamics of organizational populations, however, have not been fully appreciated.

The second assumption deserving further attention concerns our claim (summarized in Figure 3) that changes in the carrying capacity do not affect organizational vital rates instantaneously, but with at least some delay. What are the sources of this population-level inertia preventing organizational populations to adjust instantaneously to changes in the level of available resources? Consider organizational founding for example. A well-established empirical and theoretical literature recognizes that organizational founding is best conceptualized as the outcome of a complex resource mobilization process rather than an instantaneous event (Carroll and Khessina, 2005). The period during which this mobilization process unfolds is called preproduction (Carroll and Hannan, 2000; Jovanovic, 2004), or preoperational stage (Ruef, 2006). The duration of preproduction varies greatly across settings. In a comprehensive study on time to build productive capacity across several industries, Koeva (2000) reports that in the utilities sector the expected construction delay is approximately seven years. Ruef (2006), estimates that the average delay between preoperational and operational start-up in the population of US medical colleges was almost two years, but with individual times varying between a few months and 26 years.

Similar arguments may be developed for organizational mortality rates. Recognized sources of decoupling between changes in environmental conditions and observable organizational failures include uncertainty about the future, the partial irreversibility of initial investments, and the sunk costs associated with divestment decisions (Sutton, 1991). Together, these factors generate delayed responses to changes in resource conditions due to the so called "positive value of waiting" (Dixit and Pindyck, 1994). According to Bernanke (1983), the inertia built into divestment decisions derives from the two main factors: "First, individual investment projects are economically irreversible: once constructed cannot be 'undone' or made into a radically different type of project without high costs. Second, new information relevant to assessing the long-run project returns arrives over time" (1983: 86). To the extent that building organizations also involves capital investment and allocation decisions, the combination of irreversibility of initial commitments and sequential availability of information is likely to make the "value of waiting" positive and introduce unavoidable delays in processes of organizational failure.

Time delays imply that potential organizational builders and existing organizations must form expectations about future states of the environment based on available information about its current state (Lomi *et al*, 2010). To represent this process, we rely on models of adaptive expectations that were originally developed in research within the behavioral tradition (March and Simon, 1958; Cyert and March, 1963; Levitt and March, 1988) and that are routinely adopted in research on organizational performance (Greve, 2003), learning (Levinthal and March, 1981), and levels of aspirations (Lant, 1992). Let $r_t^{(e)}$ be the expected level of resources available at time t, and $r_{t-1}^{(e)}$ the level of resources that was expected in the previous time period. Finally, let r_t be the actual (observed) level of resources available at time t. Then, one form that the process of expectation formation may take is:

$$r_t^{(e)} = r_{t-1}^{(e)} + \alpha\left(r_{t-1} - r_{t-1}^{(e)}\right), \quad \text{where} \quad 0 \leq \alpha \leq 1. \tag{5}$$

In the context of processes of organizational founding, this specification implies that organization builders form expectations about (or "forecast") the future level of available resources $r_t^{(e)}$ by comparing their prior experience (r_{t-1}) with their prior expectations ($r_{t-1}^{(e)}$) and then revising their estimates by a constant fraction (α) of the difference. If $\alpha = 1$, then expectations about the future are equal to prior experience (because $r_t^{(e)} = r_{t-1}$). If $\alpha = 0$, then expectations are constant, i.e., they never change (because $r_t^{(e)} = r_{t-1}^{(e)}$). In the former case ($\alpha = 1$), potential organization builders immediately update their expectations about future levels of resources to the level that is currently observed. In the latter case ($\alpha = 0$), potential organization builders ignore observations altogether and never change their beliefs in the light of evidence. In reality, the values of α that can be estimated from data are likely to fall somewhat in between these two extreme cases (Evans and Honkapohja, 2001). When α is close to zero, reaction to new information will be slow, i.e. inertia will be high. As a consequence, the time elapsing between information and action will be long. Conversely, when α is close to 1 potential organization builders will quickly revise their estimates of future levels of resource availability in the light of current information that has become available.

Expectations play a similar role in organizational mortality rates. When $\alpha = 1$ organizations react instantaneously to changes in resources; a downturn in the relevant resource stocks will trigger an immediate wave of exits. When $\alpha = 0$, organizations are insensitive to changes in resources and will continue to operate regardless of conditions of scarcity. Expectations defined in Equation (5) enter the model as a third stock variable which takes as input the difference between resources observed and resources expected in the previous period, and produces as output current expectations about future levels of available resources. The results that we report later in the article are based on the simplifying assumption that the same mechanism of adaptive expectation formation operates symmetrically on organizational entry and exit decisions.

4. Methods

In the next section, we derive some of the qualitative implications of our arguments using computer simulation. Organizational ecology and corporate demography have long been relying on simulation methods to examine a wide variety of issues such as, for example, the evolutionary trajectories of entire organizational populations (Hannan and Carroll, 1992; Barnett, 1997), rates of organizational mortality (Lomi and Larsen, 2001), founding (Lomi and Larsen, 1996), and growth (Hannan *et al.*, 1990).

A specific advantage of simulation is the possibility of examining the full dynamics of organizational populations determined by the *interaction* among different organizational vital rates and studying their long-term implications. Empirical studies are typically limited in their ability to derive the aggregate, long-term implications of sample-specific variations in organizational vital rates that they are designed to analyze. A second advantage of simulation in the study of organizational populations is the possibility of exploring the full range of dynamic behaviors implied by a model (Carroll and Harrison, 1994). Typically, empirical studies cover a small subset of the overall space of historical possibilities. For this reason, "history-divergent models" may prove as important and insightful as "history-friendly" models (Malerba *et al.*, 1999). In empirical research these would simply be discarded as "mispecified models"—models that fail to reproduce the data accurately.

The results that we report in the next section are obtained by numerical integration using the Euler method with a fixed step as implemented in Vensim (version PLE32, 4.2a), a software package designed for system dynamics simulation. The same software makes available sensitivity analysis routines that we used in model testing. In Appendix A, we report detailed information on variable definitions, numerical values, and auxiliary assumptions needed to calibrate the model and obtain numerically meaningful results. To facilitate as much as possible comparability with prior models and to reduce the risk of reporting idiosyncratic results, the numerical values of the various parameters that we used to calibrate our baseline model are based on the simulation study of Hannan and Carroll (1992: Appendix C). Table A1 in Appendix A reports the definition and the numerical values of the parameters used to initialize the models. Table A2 reports the definition of the variables used in all the simulations (all initialized at zero). Table A3 reports the numerical range of the parameters used in the multivariate sensitivity analysis.

5. Results

Figure 4 reports some of the different evolutionary trajectories produced by the baseline model simply by varying the numerical values of the parameters controlling the strength of density dependence (the parameters in Equations 3a and 3b). With predictable differences in rates of growth and steady-state level of density, the result

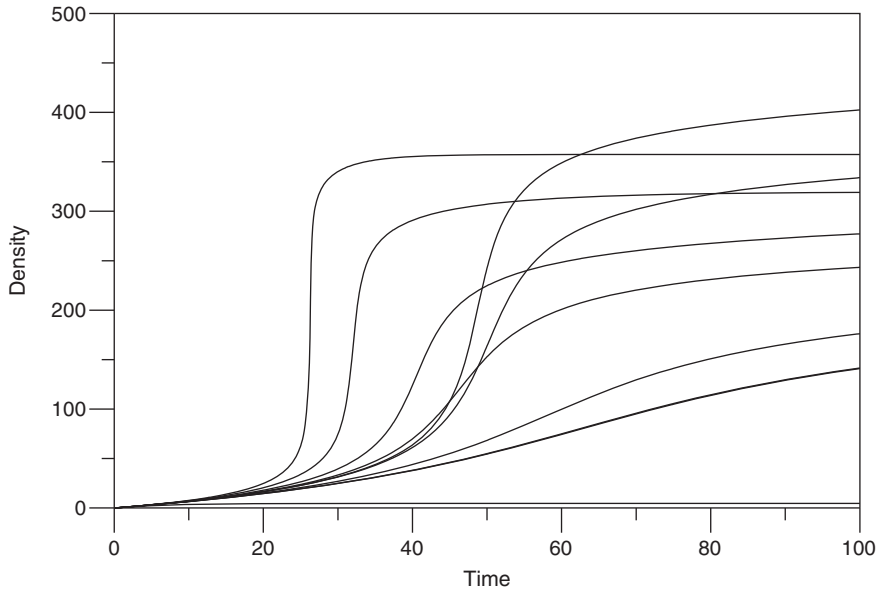

Figure 4 Historical population trajectories according to the baseline model of density dependence.

is the conventional logistic pattern typically observed in actual organizational populations (Hannan and Carroll, 1992; Barnett, 1997).

We now let the carrying capacity change. Figure 5 predictably shows that, holding everything else constant, increasing the resource regeneration rate simply increases the number of organizations that the environment may be able to sustain. Figure 5 also shows that extinction is only one possible outcome in the context of a model that is capable of producing results that are consistent with the baseline model of density dependence. When the resource regeneration rate is sufficiently high (i.e. when existing organizations contribute substantially to the stock of available resources) the population follows the more conventional pattern of logistic growth. One conclusion, therefore, is that representing extinction does not require models that are radically different but only relatively simple extensions.

The evolutionary trajectories reported in Figure 6 are obtained by varying α—the parameter which regulates the speed of expectation updating. In all cases, the population overshoots its carrying capacity, declines, and eventually goes extinct. In Figure 6a, $\alpha = 1$ i.e. adjustment is immediate. In this case, the population starts to decline soon after overshooting the carrying capacity and falls faster (due to the low inertia built in the organizational mortality rate). In Figure 6b, we set $\alpha = 0.33$ corresponding to a delay of three periods. In this case, the population will be extinct after 80 time periods. The overshoot is now more pronounced, but the decline is

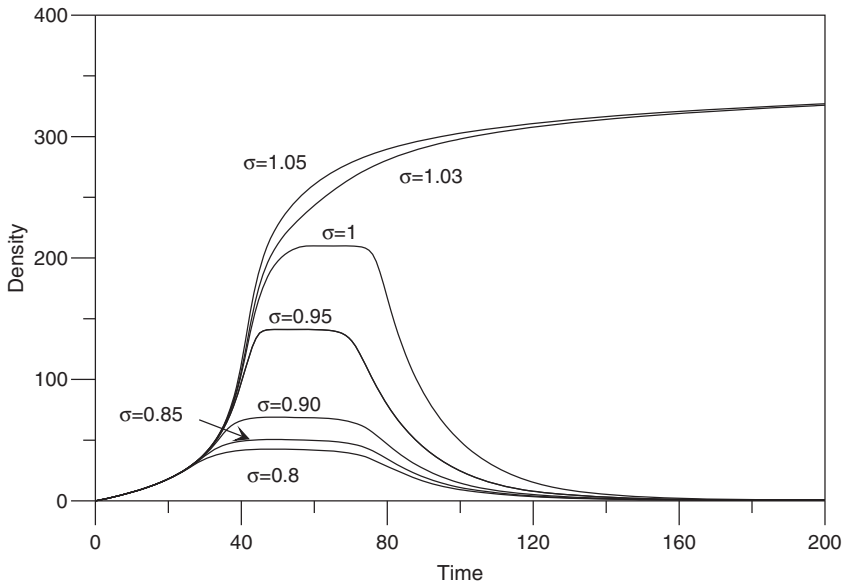

Figure 5 Effects of density-dependent resource regeneration.

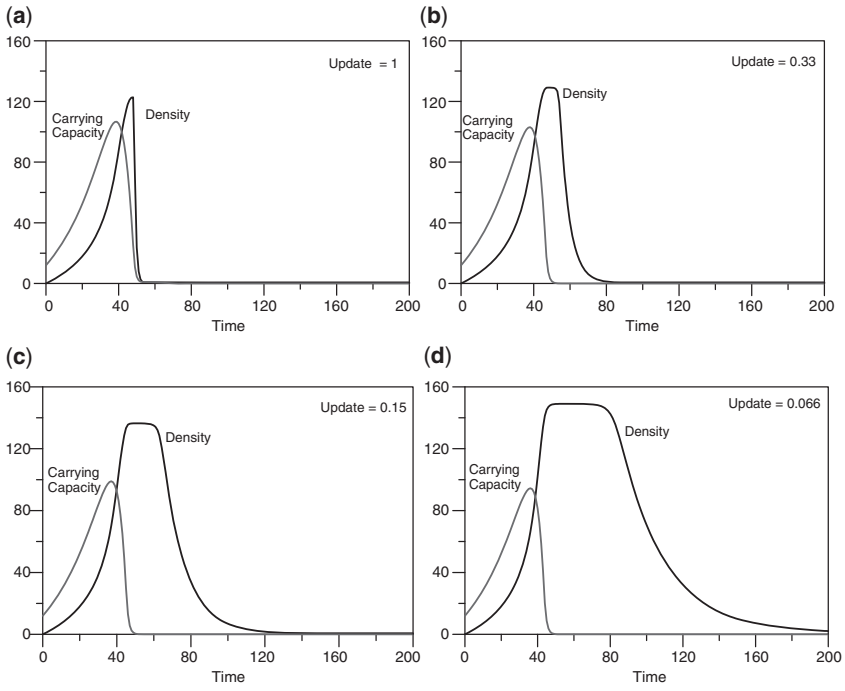

Figure 6 Trajectories of population extinction when changes in the carrying capacity affect organizational vital rates with delay. The delay time increases from panel (a) to panel (d).

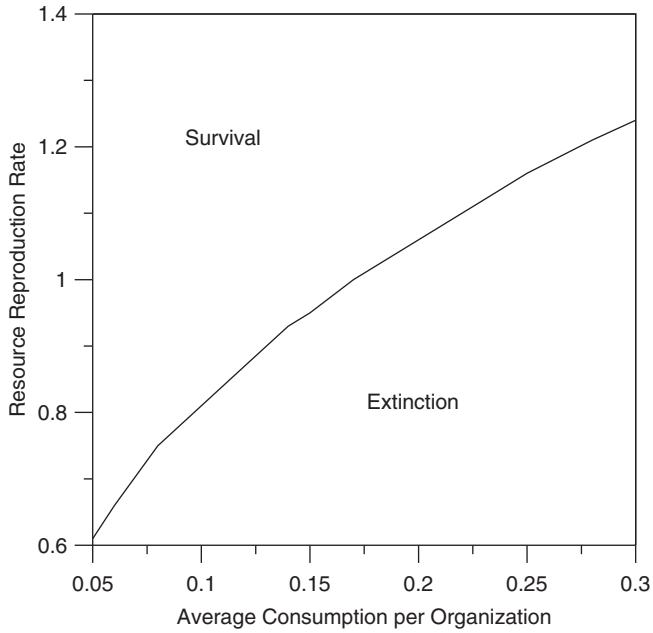

Figure 7 Phase transition diagram showing the population extinction threshold as a function of different values of resource consumption and regeneration rates.

slower due to the stickiness in organizational mortality rates implied by a diminished sensitivity to change in the level of available resources. As the delay in expectation formation increases further overshoot becomes more pronounced, decline after peak becomes slower, and time to extinction becomes longer. In Figure 6d, where $\alpha = 0.066$ (corresponding to a delay of approximately 15 time periods) the population takes more than 200 time periods before going extinct. Note that, in each case the carrying capacity follows exactly the same pattern of change over time: it increases at the beginning (due to the effect of the *resource regeneration loop*) and declines abruptly after roughly 40 time periods because of increased density (due to the dominant effect of the *resource consumption loop*).

Figure 7 shows a phase transition diagram describing the relation between (density-dependent) resource consumption and the carrying capacity regeneration rate produced by repeated simulation of the model. The horizontal axis is defined in terms of the values of the consumption rate which expresses the (average) claim that individual organizations make on environmental resources (ρ_t in Equation 4). The vertical axis is defined in terms of the resource regeneration rate. The line of equilibrium (or phase boundary), describes the conditions under which the two outcomes of interest (extinction and survival) coexist. Combinations of values on the line of equilibrium separating the two sub-spaces in the figure define the "brink of

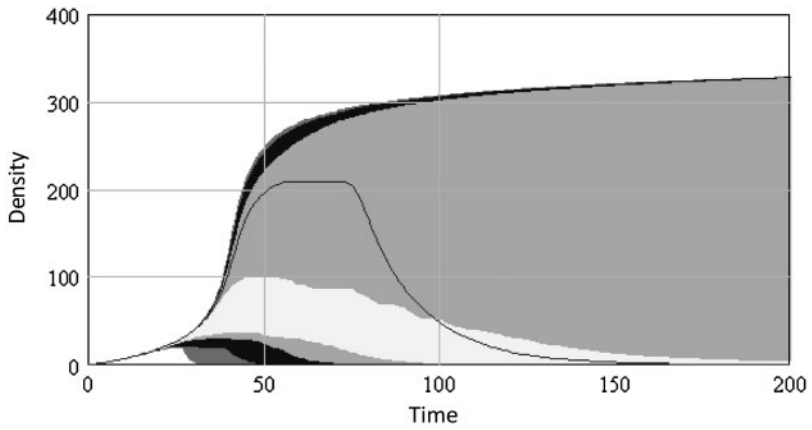

Figure 8 Multivariate sensitivity analysis (based on 250 simulations).

extinction" below which the organizational population will "run out of niche" and disappear.

The specific shape of the phase transition diagram is obviously driven by assumptions that one may be willing to make (or data that one may be willing to collect) about the specific functional form linking density to resource consumption and regeneration rates. In our model, we assumed these relations to be linear with respect to density because we wanted to keep the assumption as simple as possible. However, it is possible to think of different functional forms associated to different—and more complex—assumptions. For example, it could be that consumption and production of resources are proportional to average organizational size, or that they depend on concentration (Winter, 1990). Also, it could be possible to think that organizational consumption and production rates are not symmetrical, but are different functions of size or perhaps of characteristics of the organizational size distribution.

Figure 8 illustrates the results of a complete multivariate sensitivity analysis where all the relevant parameters are changed continuously in small increments over a (numerically) reasonable range. The results reported are based on 250 simulations. As an aid to interpretation, the different colors in the figure provide information on the distribution of the outcomes (100% of the simulations are contained within the dark grey contours, 95% within the black contours, 75% within the medium grey contours, and 50% within the light grey contours).

The results summarized in Figure 8 support three general conclusions. The first is that the model is qualitatively consistent with a considerable variety of possible trajectories including steady state equilibrium, growth and sustained decline and extinction. The second is that the model is robust to a large number of combinations of possible parameter values: in no case the model produces trajectories that would be considered empirically unusual. The third is that the results that we have reported

are not dependent on appropriately selected runs: the outcomes of the qualitative "extreme conditions testing" (Forrester and Senge, 1980) that we implemented suggest that extinction is not the outcome of idiosyncratic realizations of the simulation model. We found that no additional information is contained in the results obtained by doubling the number of simulations.

6. Discussion and conclusions

According to Aldrich and Ruef organizational populations appear and disappear with some regularity over time (2006: Chapter 9). However, no systematic empirical research and no general analytical framework are available to help students of corporate demography and organizational ecology to reflect on how these processes might be represented. While some progress has been made in understanding the emergence of new organizational forms and the appearance of new populations (Ruef, 2000; McKendrick and Carroll, 2001), with few notable exceptions little attention has been dedicated to understand the pathways to extinctions in organizational populations (Ruef, 2004b). In this article, we made a first step in this direction. While the extinction of entire organizational populations may sound like an empirically remote and ultimately uninteresting possibility, we have argued that there is considerable theoretical value in trying to understand the conditions under which current ecological models of organizations may be able to reproduce history-divergent trajectories (Malerba *et al.*, 1999). Understanding extinction of organizational forms and populations is empirically useful because we suspect that extinction may be actually more common than research has recognized so far (Ruef, 2004b).

Our models are consistent with views of population extinction as driven by endogenous population process. Similar arguments have been developed by Ruef (2004b) according to whom the demise of Southern plantations as an organizational form was not an inevitable consequence of dramatic changes in exogenous conditions brought about by the US Civil War, but was caused by endogenous forces triggered by mobilization among emancipated slaves and by competition represented by alternative forms of organization of agricultural production.

The arguments we have developed in this article also resonate with current research on the effects of sample selectivity on ecological studies of organizations. According to Denrell and Kovacs (2008) problems of selectivity arise because: "We tend to believe that the organizations and practices that populate the organizational landscape were predestined to be there" (2008: 139). We have shown that whether or not what we observe is "predestined to be there" depends on specific assumptions about the time frame in which ecological processes effectively operate, i.e. on assumption about how inertial forces decouple changes in organizational vital rates from changes in the stock of available resources. The emphasis on timing and inertia naturally led us to model expectations—beliefs that agents form about future states of their environments based on current information. This analytical strategy is

consistent with the view that "understanding challenges to organizational forms requires detailed attention to the activities and perceptions of their participants" (Ruef, 2004b: 1407).

We showed that how fast expectations are formed and can be changed has direct implications for the evolutionary trajectory that history will select and make observable. In their discussion of the implications of sample selectivity for density dependence, Denrell and Kovacs (2008) attract attention on the fact that in the evolution of organizational populations "the eventual outcome may vary substantially, depending on initial random events" (2008: 140). While we do not dispute the importance of chance, in the models we tested in this article we proposed a different explanation in which chance plays no special role. As a consequence the model allows direct experimentation with parameters more directly linked to observable individual behavior. We agree with Denrell and Kovacs (2008) that understanding the evolution of organizational populations "requires that researchers examine the full range of possible outcomes, including the many trajectories that never took off" (2008: 140). One way to think about our model is as a virtual laboratory where these various trajectories may be produced and analyzed in the context of a unified analytical framework based on the ecological model of density dependence.

The article suffers from at least five important limitations, each indicating possible directions for future research. The first limitation is that in its current version the model does not reproduce the full range of dynamic behaviors that empirical studies of organizational populations have revealed and that different models have recently attempted to investigate (Lomi *et al.*, 2010). For example, resurgence (Hannan, 1997), boom and bust cycles (Ruef, 2006) and other forms of oscillatory behavior (Ruef, 2004a) have been frequently observed in actual organizational populations, but our model is too simple to capture them. Additional experimentation is needed to understand how a model of extinction may also be able to admit resurgence as a special (and empirically important) case.

Strictly related to the first, the second limitation concerns the fact that our model contains a single population and a single stock of resources. While this starkly simplified setup allowed us to derive unambiguous conclusions on the role that time delays are likely to play in processes of extinction, it also limited the scope of our modeling exercise. More work would clearly be needed to extend the current model to multiple populations interacting through multiple resource stocks. This direction for future research is probably fruitful, but also likely to be fraught with problems deriving from the lack of clear theoretical indications about the co-evolution of multiple populations (Maynard Smith, 1986). Yet, as demonstrated by Carroll and Harrison (1994), the richness and complexity of the results that models for interacting populations afford may justify additional efforts in this direction.

The third limitation concerns our characterization of the crucial relation between density and the carrying capacity. We defined this relation as linear, but there is no

compelling reason behind this analytical choice and more complex (and realistic) assumptions should be tested in more refined versions of the model. For example, it could be that the ratio of resource consumption to resource contribution changes non linearly with organization size—a conjecture that is implicit in Winter's (1990) argument about the role of organizational size in the evolution of organizational populations. If this is the case individual differences in organizational growth rates and their aggregate outcome—concentration—would need to be determined explicitly within a much larger and complex model of population extinction.

The fourth limitation is due to the fact that the model is silent about the role of population "mass" (Barnett, 1997). This is an important issue because mass may continue to increase while density decreases. It is possible, therefore, that the evolutionary trajectory of industries characterized by different minimum efficient scales will be affected differently by mass and density-dependent processes (Zhou and van Witteloostuijn, 2010). While this is a possibility, we note that the original model of system dependence that directly inspires the current model produces an aggregate trajectory of mass that is qualitatively consistent with prior studies of mass dependence (Lomi *et al.*, 2005: 898–899).

Finally, the fifth limitation has to do with the fact that in its current state our model may at best be seen as an attempt to provide explanation for extinction as a local phenomenon. In terms of our initial motivating example sardine canning ended in Monterey, but it continued elsewhere and it continues to be a prosperous industry today. This situation is not at all uncommon in ecological studies of biotic populations that are spatially distributed (Lande, 1993) or in studies of organizational populations in which physical, geographical, or institutional boundaries isolate the local population from more general competitive and institutional processes (Hannan *et al.*, 1995; Wezel and Lomi, 2003). Since boundaries around organizational populations change over time, modeling extinction as a global process probably requires the inclusion of additional elements such as, for example, migration, diffusion, globalization and technological change. In a recent interview to the *Washington Post* (2009) sardine enthusiast, chef, and leader of the "Sardinistas" movement Mark Shelley mentioned: "Here on Cannery Row, we're eating sardines from Latvia." Including this kind of considerations in models of population extinction requires development of a large number of additional assumptions that we were unwilling to make in the context of a model designed to address a more focused—and more modest—set of issues.

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Appendix A

Indications coming from theory are rarely sufficiently detailed to define model specification uniquely. Ancillary assumptions are typically needed to translate theoretical statements about causal relations among variables into a computable (or

Table A1 Parameters of the simulation model

Parameter	Explanation	Symbol	Constraints
Consumption rate	The consumption per organization in the population	ρ	0.20
Regeneration rate	The fraction of existing carrying capacity regeneration each period	ω	0.1
Founding update weight	The weight on the new experience in expectation formation for founding	α_F	$0<\alpha_F<1$
Mortality update weight	The weight on the new experience in expectation formation for disbanding	α_D	$0<\alpha_D<1$
Multiplier of regeneration	The multiplier of the effect of density on the regeneration rate	σ	$0.6<\sigma<1.4$
Coefficient founding N		β_1	0.043
Coefficient founding N^2		β_2	−0.187
Coefficient disbanding N		θ_1	−0.023
Coefficient disbanding N^2		θ_2	0.0562

Table A2 Definition of variables included in the simulation model

Construct	Definition	Symbol	Unit	Variable Type
Organizational density	Number of organizations in a population	N_t	Number of Organizations	Stock
Organizational founding	Number of organizations entering the population in any given time period	λ_t	Number of Organizations	Flow
Organization disbanding	Number of organizations exiting from the population in any given time period	μ_t	Number of Organizations	Flow
Carrying capacity	Maximum number of organizations that a given environment can support	K_t	Number of Organizations	Stock
Resources	Expected future level of resources	$r^{(e)}$	Number of Organizations	Stock
Growth rate	Natural rate of population growth	G	Dimensionless	Constant

Table A3 Numerical range of parameters used in the multivariate sensitivity analysis

Parameter	Symbol	Range
Consumption rate	ρ	$0.05<\rho<0.3$
Founding update weight	α_F	$0<\alpha_F<1$
Mortality update weight	α_D	$0<\alpha_D<1$
Multiplier of regeneration	σ	$0.6<\sigma<1{\cdot}4$

estimable) model. To make the results reported as much as possible reproducible, in this appendix we report the numerical assumptions that we have made to set the model in motion. The implications of some of these assumptions are tested in the article. Table A1 lists the parameters in the model, their definition, and their range of variability. Table A2 summarizes the variables in the model, their unit of measurement, and their type. Table A3 reports the numerical ranges of the parameters used in the multivariate sensitivity analysis reported in the article.